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Carbon footprint of integrated waste management systems with implications of food waste diversion into the wastewater stream

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ABSTRACT

This paper introduces a comprehensive model developed to assess the carbon footprint of integrated solid waste management systems including the diversion at source of the food waste component into the wastewater/sludge management systems using household food waste disposers. In addition to the current state of practice in developed economies, the model includes emissions from waste management processes still practiced in developing economies (such as open dumping, open burning, poorly operated landfills with flaring systems and auxiliary fuel needed to satisfy the low heating value (LHV) during incineration) commonly not considered in most life cycle assessment (LCA)-based models. It can disaggregate emissions by source (from collection to final disposal), or type (direct-operating, indirect-upstream, indirect-downstream), or gas (CH_4, CO_2, N_2O) and offers users the flexibility to select processes or modify input parameters while examining their impact on uncertainty in model simulations. Equally important is a clarity in deriving and applying emission factors used to quantify emissions from waste management systems. The model was tested in the context of developed and developing economies to assess the impact of waste composition, management processes, energy consumption and other parameters on variations in emissions. The results demonstrated that best practices through material recycling, biological treatment, food waste diversion, and/or energy recovery can contribute to significant savings in emissions that ranged between 24 and 95%, depending on the tested systems. In closure, we argue the benefits of the model application in providing guidelines for policy planning and decision making about process viability for investing in carbon credit.

1. Introduction

The waste sector contributes to greenhouse gas (GHG) emissions primarily in the form of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), and a few other gases with less significant quantities. These emissions are released through various processes and components of the waste management cycle (from collection to material recovery, biological and thermal processes, and landfilling) and accounted for ~3% (1446 × 10^6 $MTCO_2E$) of worldwide GHG emissions in 2010 (Blanco et al., 2014). While relatively a smaller contributor to total GHG emissions, the waste sector is considered to present an appreciable potential towards emissions' reduction through selected technologies (Bogner et al., 2007; IFEU/Ökoinstitut, 2010) particularly in developing economies where emissions from waste can account for a larger percentage reaching 15% of total country emissions due to the greater content of highly biodegradable organics (Friedrich and Trois, 2011; IFEU/Ökoinstitut, 2010).

Over the years, several studies and models have been reported to estimate emissions from the waste sector and assess environmental burdens associated with waste management processes (Dalemo et al., 1997; McDougall et al., 2001; El Hanandeh and El Zein, 2010; Wang et al., 2012; Itoiz et al., 2013; Levis et al., 2013; Clavreul et al., 2014; EPA/ICF, 2016; Marchi et al., 2017; Thomsen et al., 2017). A review of studies (Table 1) assessing global warming factors (GWFs) for emission contribution associated with waste management show that many models targeted individual processes and provided a solid theoretical understanding about the quantification of life cycle emissions from these processes. In this context, emissions from waste management encompasses indirect *upstream* emissions arising from inputs of materials and energy (electricity & fuel), direct *operational* emissions from system operation such as onsite operating equipment and waste degradation, and indirect *downstream* emissions (or savings) related to energy generation, materials substitution, and carbon storage (Gentil et al., 2009).

Existing models have continuously evolved providing a valuable holistic approach towards understanding the functionality of waste management systems while accounting for different interactions between processes and flows. Accordingly, recent efforts included

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Table 1
Global Warming Factors per waste management process.

Reference	$MTCO_2E/1$ Ton of waste managed					
	Collection	Recycling	Composting	Anaerobic Digestion	Incineration	Landfilling
Astrup et al. (2009a)	–	Pl: −0.06 to −1.6	–		–	–
Astrup et al. (2009b)	–	–	–		0.35–0.53	–
Boldrin et al. (2009)	–	–	−0.6		–	–
Møller et al. (2009)				-0.01 to −0.004		
Cadena et al. (2009)	–	–	0.06		–	–
Chen and Lin (2008)	0.016	−2.49	0.03		−0.22	0.02
Damgaard et al. (2009)	–	Al: −5 to −19.3 St: −0.6 to −2.4	–		–	–
Eisted et al. (2009)	0.005–0.03	–	–		–	–
Friedrich and Trois (2013a,b)	0.015	−0.29 to −19.11	0.186		–	0.44 to 2.53
Hermann et al. (2011)	–	–	1.1–1.7		–	–
ISWA (2009)	–	−0.19 to −0.50	–		–	–
Kim and Kim (2010)	–	–	0.12		–	1.10
Larsen et al. (2009a)	0.004–0.03	–	–		–	–
Larsen et al. (2009b)	–	G: −0.5 to −1.5	–		–	–
Manfredi et al. (2009)	–	–	–		–	0.30
Merrild et al.(2009)	–	P: −0.4 to −4.4	–		–	–
Merrild and Christensen (2009)	–	W: −0.07 to −1.4	–		–	–
Nguyen and Wilson (2010)	0.008– 0.04	–	–		–	–
Smith et al. (2001)	0.007	–	−0.037		–	–
Range	*0.004–0.04*	*−19.3* to *−0.06*	*−0.6–1.7*	*−0.01 to −0.004*	*−0.22* to *0.53*	*0.02* to *2.53*

Pl: Plastics, Al: Aluminum, St: Steel, G: Glass, W: Wood, P: paper.

integrated systems and complex technologies (e.g. combined treatment of various waste streams and new thermal systems) (Clavreul et al., 2014; Hilty et al., 2014). However, commonly used GHG accounting models do not address certain upstream (fuel/energy and material provision) or downstream (avoided emissions from carbon storage and material recovery) processes. Additionally, commonly used models do not address emissions from certain waste management processes such as open burning or dumping and flaring of landfill gas (LFG). While such processes are seldom practiced in developed economies, they can be significant in the context of developing economies where a high fraction of the waste is still burned or disposed of in open dumps or landfilled with an inefficient LFG collection system or flared at best.

On the other hand, introducing a food waste disposer (FWD) policy to divert the organic fraction of food waste from the waste stream into the wastewater (WW) management system has proved to be an effective and economically viable alternative for waste reduction under certain conditions (Table 2). To the best of our knowledge, none of the existing models was designed to assess its impact on the emissions' inventory from the combined system of waste and wastewater including sludge management. It is worth noting that the Intergovernmental Panel on Climate Change (IPCC) guidelines for GHG emissions reporting from the waste sector includes emissions from both MSW and WW management systems and are reported under the same chapter.

While existing models have been highly recognized in assisting decision makers in defining cost effective and environmentally sound waste management alternatives, uncertainties in emission estimation seem inevitable when applied beyond their geographical boundaries where originally developed (Gentil et al., 2010; Friedrich and Trois, 2013a; Laurent et al., 2014). Equally important is the difficulty to disaggregate emissions using existing models based on scope of reporting whether for national inventorying (direct emissions) or planning and decision-making purposes (direct and indirect emissions). Hence, Gentil et al. (2010) and Friedrich and Trois (2011) recognized the need for flexible tools designed to harmonize and validate non-geographic assumptions to strengthen modeling efforts to ensure applicability in both developed and developing economies.

Building on past experience and limitations, a new model is developed with the objective to assess the impact on emissions from waste management systems when coupled with wastewater/sludge management through the introduction of a food waste disposer (FWD). The model allows the disaggregation of emissions by source (from collection to final disposal), or type (direct and indirect), or main gases (CH_4, CO_2, N_2O) and offers the flexibility of allowing the user to select processes or modify input parameters. The model was tested in the context of developed and developing economies to assess the impact of a FWD policy, waste composition and management processes, as well as input parameters towards improved planning and decision making about process viability for investing in carbon credit.

Table 2
Studies assessing the impacts of a Food Waste Disposer.

Reference	Impact coverage	Reported impact
Maalouf and El-Fadel (2017)	Carbon footprint and economic	Positive
Bernstad Saraiva et al. (2016)	Carbon footprint and energy	Positive
Yi and Yoo (2014)	Environmental and economic	Positive
Bernstad et al. (2013)	Operational	Positive
Evans (2012)	Environmental and economic	Positive
Kim et al. (2011)	Economic	Positive
Evans et al. (2010)	Operational and economic	Positive
Battistoni et al. (2007)	Operational and economic	Positive
Constantinou (2007)	Operational and economic	Negative
Evans (2007)	Environmental and economic	Positive
Lundie and Peters (2005)	Environmental	Positive
Marashlian and El-Fadel (2005)	Operational and economic	Positive
Bolzonella et al. (2003)	Operational	Negative/Positive
CECED (2003)	Operational	Negative
Diggelman and Ham (2003)	Environmental and economic	Positive
Galil and Yaacov (2001)	Operational and economic	Negative/Positive
Wainberg et al. (2000)	Operational and economic	Positive
De Koning and Van der Graaf (1996)	Operational and economic	Positive
Raunkjaer et al. (1995)	Operational	Positive
Jones (1990)	Operational	Positive
Nilsson et al. (1990)	Operational	Negative
Iacovidou et al. (2012a)	Operational and environmental	Positive
Iacovidou et al. (2012b)	Operational and environmental	Positive